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Novel Acoustic Techniques for Assessing Fish Schooling in the Context of an Operational Ocean Observatory

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LONG-TERM GOALS

Fish aggregation is important in terms of biology, fisheries, and measurement, quantitative analyses of gregarious movement behaviors remain relatively rare (Turchin 1989). Fish aggregation has most often been studied in easily accessed fish or fish easily maintained in the laboratory such as minnows and dace (see a review in Pitcher and Parrish 1993). Measurements of fish aggregations are often difficult, particularly in pelagic environments. Our goal is to develop new acoustic techniques that have the potential to serve as measurement tools to quantify this ubiquitous and important behavior.

OBJECTIVES

This project brings together a team with expertise in acoustics, engineering, biology, fisheries, and oceanography to develop and apply acoustic techniques to measure schooling in pelagic fish. We combined traditional, split-beam fisheries echosounding techniques and direct sampling with new acoustic techniques and new platforms in a study area monitored by an existing operational ocean observatory. To measure synoptic distributions of fish schools we collected mid-frequency back- and bistatic-scattering from fish using a unique horizontally oriented multibeam system. We will experimentally evaluate the use of ship-board and moored mid-frequency sonar for the detection and resolution of fish schools at long range (kilometer scale) in the context of propagation and scattering in a shallow water waveguide. Toward the goal of integrating mid to geometric frequency scattering measurements, we will observe the relationship of high frequency echosounder and multibeam measurements to mid-frequency short-range measurements (direct path scattering) and mid-frequency long-range measurements (waveguide scattering). In doing so, we will correlate the results of the longer-range measurement (less understood and more complex scattering geometries) with more traditional (better understood) higher frequency and geometric scattering regimes and techniques. We will also investigate the ability of higher frequency multibeam techniques to assess the internal structure of detected schools. A 200 kHz multibeam capable of collecting water column data will be integrated into an autonomous underwater vehicle (REMUS). Deploying this cutting edge instrument on an autonomous platform will allow us to access fish at greater depths, while sampling the high spatial resolution necessary to measure the geometry of fish in an aggregation. All field sampling will be conducted within the New Jersey Shelf Observing System (NJ SOS), which provides real-time data throughout the Mid-Atlantic Bight (MAB). The surveys will be positioned adaptively using real-time

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14. ABSTRACT

Fish aggregation is important in terms of biology, fisheries, and measurement, quantitative analyses of gregarious movement behaviors remain relatively rare (Turchin 1989). Fish aggregation has most often been studied in easily accessed fish or fish easily maintained in the laboratory such as minnows and dace (see a review in Pitcher and Parrish 1993). Measurements of fish aggregations are often difficult, particularly in pelagic environments. Our goal is to develop new acoustic techniques that have the potential to serve as measurement tools to quantify this ubiquitous and important behavior.

15. SUBJECT TERMS

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data collected with the international constellation of ocean color satellites, a nested grid of HF radars, and an operational fleet of autonomous Webb Gliders. The goal is to use the environmental data to optimize ship and AUV acoustic surveys by using the observatory to identify specific water masses, frontal boundaries, and subsurface phytoplankton plumes. The surveys will then identify and track schools of fish associated with this hydrographic and biological structure. This approach will provide a context for the fish schooling information, allowing us to begin to look for correlations between the fish biology and environmental variability.

APPROACH

- *Develop new acoustic techniques to measure aggregations of fish*
  - High-frequency multibeam sonar on autonomous underwater vehicle (AUV)
    - Observe individual schools over short ranges
    - Quantify geometry inside of school
  - Mid-frequency multibeam sonar
    - Image large volume of water
    - Quantify gross school movement
    - Back and bistatic-scattering

- *Relate mid-frequency acoustic bistatic and back scattering to high-frequency multibeam and split-beam backscatter and both to fish activity*
  - Determine how fish distribution (school structure) is related to long-range acoustic scattering
  - Use traditional techniques with new methods to determine which fish are present, in what numbers, and how they are distributed
  - Determine how variability within a school affects acoustic scattering

- *Relate fish causing acoustic scattering to physical and biological oceanography*
  - Characterize environment for different fish schools using the New Jersey Shelf Observing System

- *Obtain time series data*
  - Diel patterns in distribution of fish
  - Changes with physical environment

WORK COMPLETED

Development of two new sonar systems has been completed. Three field efforts were conducted as part of this work.

The first paper resulting from this work was published this year:

Benoit-Bird, K.J., Au, W.W.L., Wisdom, D.W.* 2009 “Nocturnal light and lunar cycle effects on diel migration of micronekton.” Limnology and Oceanography 54: 1789-1800

Two other papers are currently in review:

Benoit-Bird, K.J., Moline, M.A., Schofield, O.M., Robbins, I.C, Waluk, C.M. “Zooplankton avoidance of a profiled open-path fluorometer.” In review.

Benoit-Bird, K.J. “Validation of scattering models for elastic shelled animals using multi-frequency, in situ measurements of backscatter from pteropods.” In review.

RESULTS

2008 Field Effort

Numerous small schools of fish and their habitat were measured in Monterey Bay using the echosounders, multibeam sonar, PIMMS, gliders, CTDs, and nets. An example of data collected with the 120 kHz echosounder is shown in Figure 1.

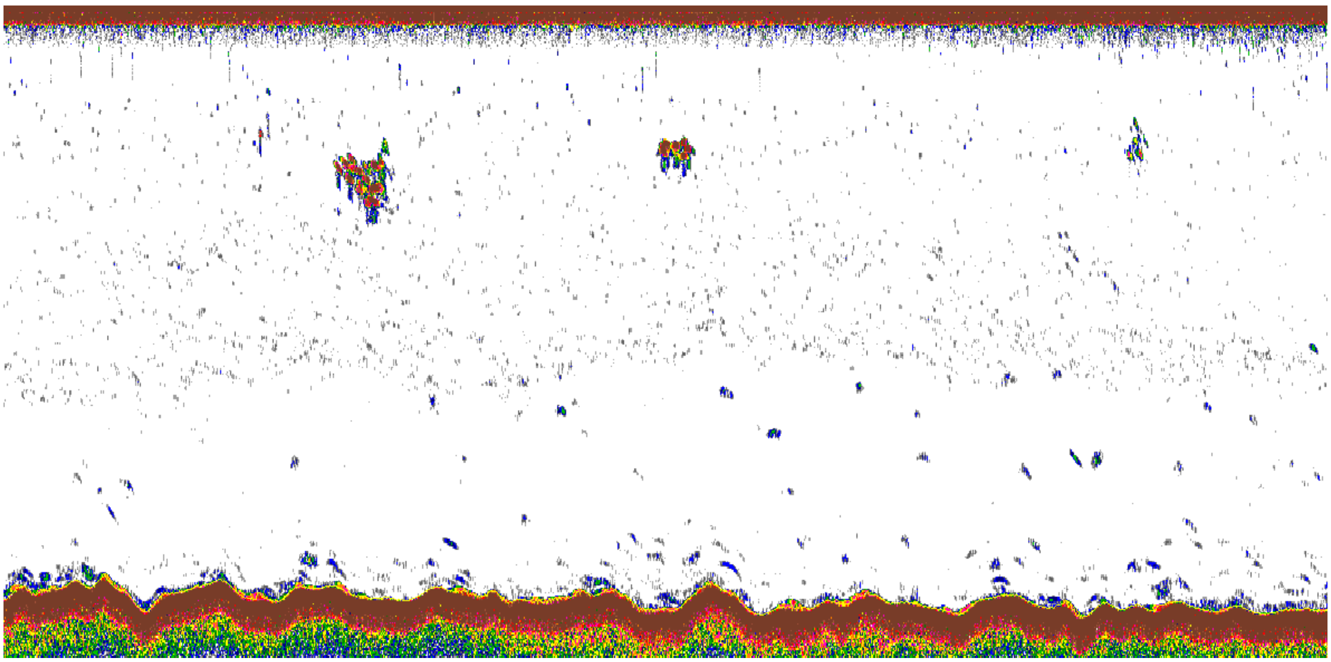

Figure 1. An example of fish schools imaged with the 120 kHz echosounder is shown. The total echogram is 250 m across and 20 m in depth. The backscattering intensity is shown in color with red representing strong scattering. Strong scattering from the seafloor is noticeable near the bottom of the echogram while strong scattering in the middle of the water column is from small schools of fish, likely sardines and anchovies.

These measurements provided the final example of targets necessary for verification of the performance of PIMMS and the new multibeam sonar.

As part of the 2008 field efforts, we also measured the amount of nocturnal light using light sensors developed during the 2007 field season.

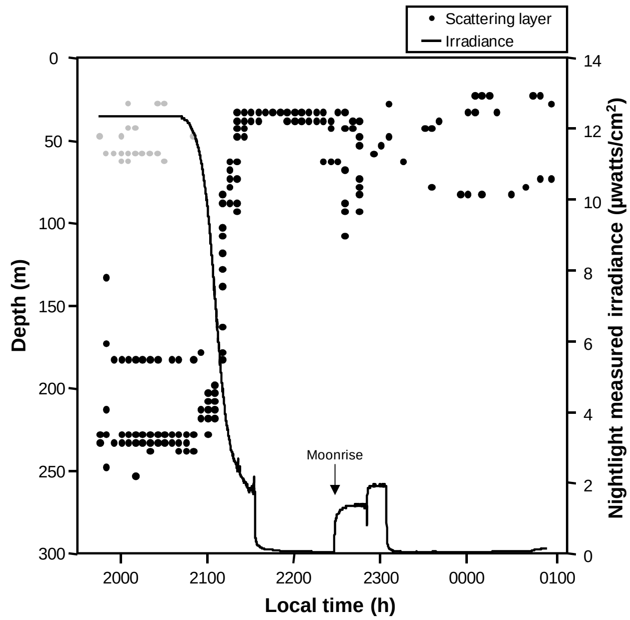

Figure 2. The depth of volume scattering layers detected with a 70 kHz split-beam echosounder (points) along with a plot on a log scale of light from a Nightlight (solid line) as a function of local time. The main scattering layers are indicated by the black points. A thin backscatter layer with a distinct frequency response that was not observed after sunset is indicated by light grey points. Note the inverse relationship of the scattering layer's depth and the light level available both after sunset and after moonrise.

These light sensors were used to examine the roles of nocturnal light and lunar phase in the diel migration of micronekton from a nearshore scattering layer. Migration patterns were measured over six complete lunar cycles using moored upward-looking echosounders while nocturnal surface irradiance was recorded. We hypothesized that animals would remain at a constant isolume at night despite changes in nocturnal illumination between nights. The scattering layer migrated closer to the surface during dark nights than well-lit ones. However, this movement was not enough to compensate for observed changes in light, and at night animals often remained at light levels higher than they experience at depth during the day. Light and lunar cycle were not completely coupled, allowing separation of the light and lunar phase. Contrary to the initial hypothesis, lunar phase accounted for substantially more of the variability in layer migration than surface irradiance, showing strong effects on the scattering layer's depth and animal density within the layer. Changes in layer depth and animal density were amplified a small amount by variations in light level but were minimized by the seafloor in shallow areas. The horizontal component of the scattering layer's migration was also affected by lunar phase with animals remaining further offshore, in deeper waters during nights near and during the full moon, even when these were not the nights with the highest light levels. These results suggest that moonlight may be a cue for an endogenous lunar rhythm in the process of diel migration rather than a direct cause.

2007 Field Effort

The 2007 field effort off the Hudson Canyon area revealed very low fish biomass. However, there were incredible patches of pelagic snails in the water column that were intense sources of acoustic

scattering. These snails showed scattering as intense as dense schools of fish, suggesting their importance in the interpretation of acoustic data. A manuscript describing the acoustic scattering from these snail swarms is currently in review.

IMPACT/APPLICATIONS

The distribution of fish and the variability in their distribution has implications for fisheries, stock assessment, and operational acoustic techniques. This is particularly true in continental shelf regions where fish densities are high and their distribution is highly patchy. This work will provide basic information on the structure of fish aggregations, the effects of fish aggregations on both mid and high frequency acoustics, and the relationship between mid frequency acoustic scattering and more traditional, relatively well-understood high frequency acoustic scattering. In addition, we will examine the correlation between fish, important biological sources of acoustic scattering, and environmental variability by utilizing the existing resources of the New Jersey Shelf Observing System (NJ SOS). An understanding of the relationship between fish and their habitat will provide the opportunity to make predictions about the distribution of fish aggregations at the scale of the study region and the distribution of fish within an individual aggregation. This will contribute to our efforts model scattering from biological sources. We expect this work will allow us to develop new acoustic techniques, that expand our understanding of the basic biology of fish, understand the relationship between fish aggregation characteristics and acoustic scattering at mid and high frequencies, relate more traditional high frequency techniques to more complex scattering at mid frequencies, and explore the potential of mid frequencies in both direct and waveguide scattering for application to fish.

REFERENCES

Pitcher, T. J., and J. K. Parrish. 1993. Function of shoaling behavior in teleosts, p. 363-439. In T. J. Pitcher [eds], Behavior of teleost fishes. Chapman and Hall.

Turchin, P. 1989. Population consequences of aggregative movement. J. Anim. Ecol. **58:** 75-100.